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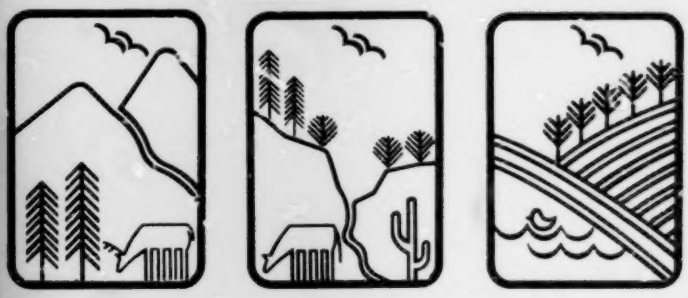

Research Note RM-472

August 1987

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USDA Forest Service

Rocky Mountain Forest and Range Experiment Station

Predicting Reduction of Natural Fuels by Prescribed Burning Under Ponderosa Pine in Southeastern Arizona

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Results from 10 prescribed burns conducted under different weather and fuel conditions in ponderosa pine stands in southeastern Arizona indicate that forest floor fuel consumption can be estimated using H-layer moisture content, and either preburn forest floor depth or stand density. Equations presented give forest managers the ability to estimate, and thus prescribe, amounts of fuel that would be consumed by prescribed fire or unplanned ignition.

Keywords: Prescribed fire, forest fuels

Management Implications

Forest managers are frequently faced with situations of abnormally large fuel accumulations that create fire hazards and reduce site productivity. The use of planned prescribed fire, primarily to relieve these problems, is increasing. In addition to planned ignitions, the USDA Forest Service has implemented a revised fire policy that permits unplanned ignitions to burn in specific areas which may contain fuel hazards if negative resource impacts are minimal and conditions fall within specific burning prescriptions. Managers recognize that certain amounts of fuels should be removed in order to maintain productive sites. If too little fuel is consumed, the fuel hazard is still present; if too much is consumed, site damage can result. Therefore, the ability to predict amounts of fuel reduction using preburn site characteristics would be valuable.

If the manager decides to use prescribed fire to reduce forest floor fuel hazards, the regression equations reported here can be used to help reach those goals. Equation 2 is preferred and requires H-layer moisture content and forest floor depth. The manager must first decide what percent forest floor reduction is desired. Forest floor depths for distinctly different sites within the proposed burn area can then be measured. The equation can then be used to calculate the H-layer moisture content that would be required during burning to achieve the preferred fuel reduction. At this point, only the H-layer need be sampled at regular intervals until the desired moisture content is reached. Then if other fuel and weather conditions fall within the prescription range reported here, the prescribed burn can be conducted. Under the fuel, stand, weather, and slope conditions described here, only downslope backing fires should be used.

Introduction

The forest floor, defined as dead organic matter lying on the mineral soil, can greatly influence site characteristics. Amounts of forest floor material can affect density and vigor of understory vegetation; chemical, physical, and biological features of the soil; and fire behavior and effects. If forest floor reduction by fire is deemed necessary to improve site quality or to reduce the fire hazard, the ability to predict amounts of forest floor consumed would be valuable.

Research in various forest types of the West has demonstrated that the reduction by prescribed fire of forest floor or duff can be predicted. Norum (1977) indicated that duff reduction was highly dependent upon the moisture content of the lower half of the duff itself. In addition, knowledge of the amounts of woody fuels consumed improved upon the estimation of duff reduc-

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tion. Sandberg (1980) also found duff moisture to be most important in predicting duff consumption under slash; he used National Fire-Danger Rating (NFDR) moisture values, as described in Deeming et al. (1977), to predict duff reduction as well. Including preburn duff amounts further improved predictions of duff reduction. In a comprehensive study of prescribed burns in the northern Rocky Mountains, Brown et al. (1985) found that absolute duff depth reduction, percent duff depth reduction, and percent mineral soil exposed could be accurately predicted if the moisture content of the lower half of the duff was known; these same values could also be adequately estimated for general guidance using National Fire-Danger Rating 1,000-hr moisture values.

The research reported here was undertaken to develop methods for estimating forest floor loading reductions resulting from the use of prescribed fire using stand, fuel, and weather conditions in southeastern Arizona ponderosa pine stands.

Methods

The study sites were on southwest-facing, 30–50% slopes in the Santa Catalina Mountains in southeastern Arizona. Annual precipitation at this 8,000-foot elevation averages 30 inches. The forest, which is dominated by ponderosa pine (*Pinus ponderosa* vars. *scopulorum* and *arizonica*), is composed primarily of uneven-aged stands with relatively even-aged groups.

From June through September in 1979 to 1981, 10 prescribed burns were conducted over a range of stand and environmental conditions. The main criteria for burn site selection were lack of human disturbance and relatively homogeneous vegetation.

A series of plots, approximately 0.1 acre in size, were randomly established within the selected sites on which the fuels and stand were measured. Each plot consisted of a systematic 3 by 3 grid with each of the nine sample points spaced 20–25 feet apart. At each sample point, a 1-square-foot sample of the forest floor, including all needle and woody material less than 1 inch in diameter, was collected. The oven-dry weight per unit area or loading was determined.

Downed woody fuels 1–3 inches in diameter were sampled along three permanent transects placed across the plots between sample points. Intercepts of fuels in this size class were counted, and a weight per area determined using Brown's (1974) method. The length and mid-diameter of all woody fuels greater than 3 inches in diameter were measured within a 0.05-acre circle, centered at the plot center. Fuel volumes were computed using lengths and diameters, and weights were determined using accepted densities of either sound or rotten woody material.

Because of the severe fire hazard created by fuel and slope conditions, downslope backing fires were used exclusively. During the burning, six samples per plot were collected from each of the three distinct forest floor layers for moisture content determination. The L-layer (litter) is the newly fallen surface fuel. The F-layer (fermentation) consists of material in the early stages of decomposition and weathering. H-layer (humus) fuels are in the advanced stages of decomposition, immediately above the mineral soil, where separate fuel components are difficult to distinguish.

Analysis

To determine the predictability of fuel reduction, a series of independent variables were tested using multiple linear regression in a stepwise fashion. The dependent variable was percent reduction of forest floor loading (weight per unit area), and the independent variables tested were H-layer moisture content, preburn forest floor depth, number of trees greater than 0.5 inch d.b.h. per acre, large woody fuel loading reduction, NFDR 100-hr moisture values, and basal area per acre.

Results and Discussion

Table 1 lists the range of preburn site characteristics and conditions found on all study sites and used in the development of the regressions. The succeeding regressions are not applicable to sites with conditions beyond these ranges. The H-layer moisture content had the highest correlation with percent forest floor loading reduction:

$$FR\% = 89.92 - 0.55\ HM \quad [1]$$
$$(r^2 = 0.62,\ S_{y.x} = 13.06)$$

FR% = forest floor loading reduction (percent)
HM = H-layer moisture content (percent).

However, the large standard error indicates that a great deal of variability exists. Therefore, the usefulness in estimating forest floor reduction with this single variable is marginal. The predictability of fuel loading reduction was progressively improved by adding other preburn site characteristics to the regression.

The second most important controlling factor in forest floor reduction is forest floor depth:

$$FR\% = 37.37 - 0.75\ HM + 21.19\ FD \quad [2]$$
$$(r^2 = 0.91,\ S_{y.x} = 6.74)$$

FD = preburn forest floor depth (inches).

A positive correlation implies that with uniform moisture, an increasing percentage of fuel reduction can be expected with increasing forest floor depth. Sweeney and Biswell's (1961) study with ponderosa pine fuels also showed increasing consumption with increasing fuel amounts, except when fuels were quite moist. However, Sandberg (1980) showed that under constant moisture conditions, percent duff depth reduction was less on sites with greater preburn duff depths in Douglas-fir fuels. Differences between natural ponderosa pine fuels and Douglas-fir slash fuels may help explain this discrepancy.

No third variable added to equation 2 significantly improved upon its predictability. However, other variables included with H-layer moisture content produced usable

Table 1.—Range of site characteristics found in 10 experimental burn units in the Santa Catalina Mountains.

Site characteristics	Mean	Range	Standard deviation
Forest floor fuel reduction (percent)	59.0	19.1 - 92.8	20.0
Preburn forest floor loading (tons per acre)	29.5	24.7 - 40.5	5.0
Preburn forest floor depth (inches)	3.0	2.2 - 4.0	0.6
1- to 3-inch woody fuels (tons per acre)	1.0	0.6 - 1.9	0.5
>3-inch woody fuels (tons per acre)	7.7	2.6 - 15.0	3.9
Trees >0.5-inch d.b.h. per acre (number)	1526	837 - 2193	412
Basal area (square feet per acre)	220	171 - 278	36
H-layer moisture content (percent)	56.2	16.5 - 109.9	28.7

and significant relationships worth mentioning, even though equation 2 is the preferred regression.

When number of trees greater than 0.5-inch d.b.h. is included with H-layer moisture, a highly significant relationship results:

$$FR\% = 141.68 - 0.72\ HM - 0.03\ TA \quad [3]$$
$$(r^2 = 0.89,\ S_{y.x} = 7.41)$$

TA = number of trees > 0.5-inch d.b.h. per acre.

A negative correlation signifies that the sites with the greatest tree densities will have the least fuel reduction, other conditions remaining constant. Harrington (1981) pointed out that the fuels under more dense stands are frequently wetter than those under less dense stands. Therefore, the same conditions created by tree density that affect fuel moisture may also be affecting the degree of fuel consumption directly. Dense stands produce more shade, which in turn lowers air and fuel temperatures and raises humidities (Countryman 1977). Rothermel (1983) indicated that dense stands reduce air movement and, therefore, could reduce fire aeration. These factors would likely result in less fuel consumption.

Previous research has shown that variables other than the three discussed above can be useful in estimating fuel reduction. Norum (1977) found that consumption of 0- to 3-inch woody fuels had an effect on percent duff depth reduction because of the duff preheating and drying. Brown et al. (1985) noted that this situation likely occurs only in natural fuels because knowledge of woody slash fuel consumption does not improve prediction equations for duff reduction once duff moisture content is known. In the present study, woody fuels less than 3 inches in diameter averaged only 2.5 tons per acre; therefore, their consumption had little effect on forest floor reduction. However, larger woody fuels ranged from 2.6 to 15.0 tons per acre, and their consumption ranged from 1.8 to 9.0 tons per acre. If consumption of woody fuels greater than 3 inches in diameter is used with H-layer moisture, the fuel reduction estimation regression becomes:

$$FR\% = 79.15 - 0.53HM + 2.33WR \quad [4]$$
$$(r^2 = 0.73,\ S_{y.x} = 11.88)$$

WR = > 3-inch woody fuel loading reductions (tons per acre).

This equation shows that the consumption of large woody fuels leads to additional forest floor consumption. The lengthy burning of the woody fuels exposes the forest floor to long periods of heating and drying. The prediction accuracy is improved over equation 1 with H-layer moisture only. However, because of the added efforts in measuring woody fuels before and after burning, and because of the great variability in natural woody fuel loadings, measurement of their consumption and therefore the use of this equation is not recommended. Managers should be aware, however, that when greater than average woody fuel loadings occur in an area, greater forest floor fuel reduction will likely result than predicted by equations 1, 2, or 3.

For fuel managers to use the recommended prediction equations, the independent variables must be measured. It should be noted that the equations should be used only in situations similar to those described in table 1. Equation 2 is preferred over equation 1 or 3, and 3 would be preferred over equation 1. Regardless, the most important variable to know is the moisture content of the H-layer. Ideally, the humus layer should be directly sampled for moisture content. Potts et al. (1986) have developed duff sampling guidelines that should be useful in most fuel types. As substitutes for actual fuel moisture measurements, NFDR 1,000-hr moisture values were accurate for predicting duff reduction in the Pacific Northwest (Sandberg 1980). Sandberg indicated that the 1,000-hr moisture values were more useful than actual duff moisture measurements because of the great variability of duff moisture and difficulty of collecting samples. However, Brown et al. (1985) reported that the 1,000-hr moisture values predicted duff reduction with adequate precision for only general guidance.

In this study, NFDR moisture values were not calculated during the 10 prescribed burns. However, 1,000-hr and 100-hr moisture values were determined and regressed against actual H-layer moisture in another study on the same sites. The 100-hr moisture values provided the only reasonable correlation:

$$HM = -30.64 + 5.86\ HH \quad [5]$$
$$(r^2 = 0.82,\ S_{y.x} = 12.95)$$

HH = 100-hr moisture value (percent).

This relationship is marginally useful because the moisture content can only be estimated within ±25% moisture of the mean at the 95% confidence level. Again, actual H-layer moisture should be measured.

Forest floor depth is the next important variable to be considered. Even though the equations are predicting percent reduction of forest floor loading, preburn forest

floor depths are easier to measure and produce a more precise prediction equation than preburn loading. About 10 depth measurements should be randomly taken and averaged within smaller units of the proposed burn area. The smaller units should be divided where abrupt tree density changes occur.

If equation 3 is used as a second choice to equation 2, tree density must be measured in the area designated for prescribed burning. Tree size does not appear to be additionally important because the inclusion of basal area per acre with H-layer moisture did not improve the correlation with fuel reduction over H-layer moisture alone. Tree density should be measured within smaller units of the large areas proposed for burning. Again, these smaller units should be divided where abrupt changes in tree density occur.

Equations 1, 2, or 3 should only be used to predict fuel consumption if the general weather and burning conditions described by Harrington (1981) exist. These conditions specify downslope backing fires with air temperatures between 55° and 75° F, relative humidities between 25% and 50%, and winds, upslope, between 1 and 5 miles per hour. In addition, the surface L-layer fuels should contain between 5% and 9% moisture.

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